

# Future Upgrade and Physics Perspectives of the ALICE TPC

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## Abstract

The ALICE experiment at the Large Hadron Collider (LHC) proposes major detector upgrades to fully exploit the increase of the luminosity of the LHC in RUN 3 and to extend the physics reach for rare probes at low transverse momentum. The Time Projection Chamber (TPC) is one of the main tracking and PID devices in the central barrel of ALICE. The maximum trigger rate of the TPC is currently limited to about 3.5 kHz by the operation of a gating grid system. In order to make full use of the luminosity in RUN 3, the TPC is foreseen to be operated in an ungated mode with continuous readout. The existing MWPC readout will be replaced by a Micro-Pattern Gaseous Detector (MPGD) based readout, which provides intrinsic ion capture capability without gating. Extensive detector R&D employing Gas Electron Multiplier (GEM) and Micro-Mesh Gaseous detector (Micromegas) technologies, and simulation studies to advance the techniques for the corrections of space-charge distortions have been performed since 2012. In this paper, the expected detector performance and the status of the R&D program to achieve this ambitious goal are described.

**Keywords:** Heavy-ion Collisions, Quark-Gluon Plasma, ALICE, Time Projection Chamber, Micro-Pattern Gaseous Detector

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## 1. ALICE Upgrade after LS2

The ALICE experiment is dedicated to the studies of the properties of the deconfined QCD medium (Quark-Gluon Plasma, QGP) by conducting ultra-relativistic heavy-ion collisions at the LHC [1]. A significant increase of the luminosity for heavy ions is expected in RUN 3 after Long Shutdown 2 (LS2), which implies a collision rate of about 50 kHz and  $\mathcal{L}_{\text{int}} = 10 \text{ nb}^{-1}$ . This luminosity upgrade provides a substantial enhancement of capabilities for measuring observables relevant to the characterization of the QGP at the highest temperatures [2].

In order to exploit the scientific potential of the high-luminosity heavy-ion program in RUN 3, ALICE plans to extend its physics reach by upgrading the ALICE detector. The major goals of the upgraded ALICE detector are as follows; precision measurements of heavy-quark and quarkonia production at low transverse momentum ( $p_T$ ) to study the mechanisms of heavy-quark thermalization and interactions in the medium, production of low-mass dielectrons to extract information on thermodynamical properties of the medium and to characterize the chiral phase transition, jets and jet correlations to reveal the mechanisms of partonic energy loss in the medium [2].

## 2. ALICE TPC Upgrade

The Time Projection Chamber (TPC) is one of the main tracking and PID devices in the central barrel of the ALICE detector. It provides precise charged-particle tracking, momentum measurement, and particle identification in very high multiplicity heavy-ion collisions [3].

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<sup>1</sup> A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

The readout rate of the TPC is currently limited by the necessity to prevent ions generated in the the amplification region of the MWPC-based readout chambers from drifting back into the drift volume, which is achieved through active ion gating by operating a dedicated gating grid. The relevant ion drift times limit the maximum trigger rate of the TPC to about 3.5 kHz.

Operation of the current TPC with the MPWC-based readout scheme and the current active ion gating scheme at 50 kHz Pb-Pb collisions in RUN 3 cannot be possible. On the other hand, operation of the current TPC with continuously open gating grid cannot be the solution since back-drifting ions from the amplification region will lead to excessive ion charge densities and distortions of the electric field in the drift volume. The proposed scheme to acquire high rate operational capability and a small number of back-drifting ions is to replace the existing MWPC-based readout chambers and gating grid system by a multi-layer Gas Electron Multiplier (GEM) system and to run the TPC in an ungated continuous mode. GEMs have been developed to cope with the stringent requirements for high-luminosity experiments [4] and have proven to provide excellent position resolution, to have very high rate capability, and better ion blocking capability compared to MWPC. The main considerations for the TPC upgrade and the design requirements are as follows [5]:

- The maximum ion backflow (IBF) that can be tolerated is about 1% at a gain of 2000 in Ne-CO<sub>2</sub>-N<sub>2</sub> (90-10-5), i.e. 20 back-drifting ions per incoming primary electron ( $\epsilon = 20$ ).
- In case of IBF = 1%, space-charge field distortions reach 20 cm and 8 cm in  $r$  and  $r\phi$  at small  $r$  and  $z$  ( $|\eta| \sim 0$ ) in the TPC, respectively. In order to preserve the present momentum resolution, online and offline distortion corrections with a precision better than 500  $\mu\text{m}$ , i.e. a few times  $10^{-3}$ , are required.
- Due to the limited bandwidth of the data acquisition system, reduction of data flow size by a factor of 20 is needed in the online reconstruction by finding the clusters associated to tracks.
- The upgraded TPC must preserve the performance of the existing system in terms of particle identification via  $dE/dx$ , implying a local energy resolution better than 12% (at 5.9 keV).

### 3. Status of R&D Activities

An extensive R&D program has been started in 2012 to study the performance of GEM-based detectors (IBF, gain stability, discharge probability), technology choice (GEM stacks including the combination of GEMs with different pitches, COBRA-GEM, 2 GEM + Micromegas system), large prototype production by single mask technology, electronics R&D, and simulation studies to establish the strategy for space-charge distortion corrections.

Our baseline solution comprises stacks of 4 GEM layers, where 1st and 4th GEMs are standard GEMs with 140  $\mu\text{m}$  pitch, 50  $\mu\text{m}$  thickness, and 70 (50)  $\mu\text{m}$  outer (inner) hole diameter, and 2nd and 3rd GEMs are large pitch GEM foils with 280  $\mu\text{m}$  pitch, 50  $\mu\text{m}$  thickness, and 70 (50)  $\mu\text{m}$  outer (inner) hole diameter. This setup allows to block ions efficiently by employing low/high fields above/below GEMs and foils with low optical transparency. Figure 1 shows the results of the measured IBF and energy resolution at 5.9 keV at a gain of 2000 for a 4-GEM system, where the voltage across GEM1 increases from left to right along the x-axis. It can be seen that an IBF of 0.7% is achieved at an energy resolution of 12% (at 5.9 keV) The observed anti-correlation between IBF and resolution is related to the gains of the first two GEMs: higher electron multiplication at the early stages improves the energy resolution, while it results in larger number of ions escaping into the drift region.

Detailed simulations based on Garfield++ [6] were performed to describe the observed IBF performance. It was found that IBF is very sensitive to the alignment of the GEM holes in consecutive layers, which can not be controlled experimentally. The measured IBF values are best reproduced in simulations, if a random misalignment of the holes is assumed, corresponding to the most probable relative geometrical position of GEM foils in a stack.

A prototype of an Inner Readout Chamber of the TPC (IROC) was built in 2012, where triple stacks of GEMs were produced using the single-mask technology developed by the MPGD workshop at CERN. Beam test was carried out at the PS-T10 beamline and the  $dE/dx$  resolution was studied as function of the transfer fields and voltages across GEMs. Figure 2 shows the  $dE/dx$  spectra of 1 GeV/c electrons and pions recorded at a gain of  $\sim 5000$ . The energy resolution is 10.5% for the IBF-optimized field configurations and the resolution is comparable to the  $dE/dx$  resolution of the current TPC.

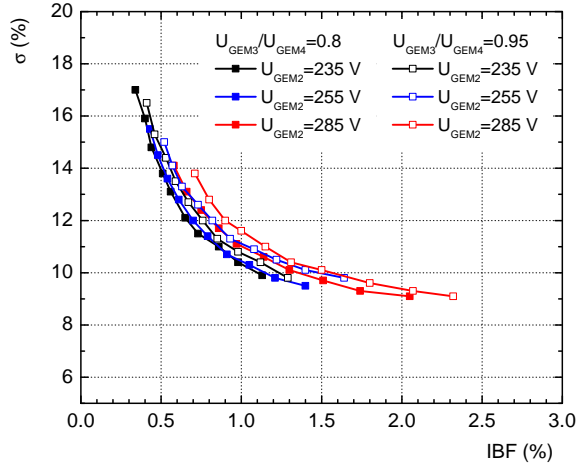


Figure 1. Correlation between IBF and energy resolution at 5.9 keV in a 4 GEM setup (S-LP-LP-S) in Ne-CO<sub>2</sub>-N<sub>2</sub> (90-10-5) for various settings of voltage of GEM2.

An alternative solution is a system combining 2 GEMs with a Micromegas detector. Micromegas (MM) provides low IBF due to the larger ratio of the electric field values in the small amplification gap to the drift field above the MM. If the MM employs a fine mesh (400-1000 LPI), IBF is close to the ratio between two fields itself [7]. The IBF and energy resolution for this hybrid 2-GEM + MM system were measured, using a  $10 \times 10 \text{ cm}^2$  prototype detector. The results are shown in Fig. 3, where an IBF of 0.2% is reached at an energy resolution of 12% at 5.9 keV. A large-scale solution for the inner and outer TPC readout chambers and the operational stability will be verified in the future.

The new scheme also required the development of new front-end electronics to cope with the reversed polarity, the requirements for continuous readout, and the increased data throughput in high rate Pb-Pb collisions. A new front-end ASIC called SAMPA has been developed, which integrates the functionality of the present preamp/shaper and ALTRO ADC+DSP (Digital Signal Processing) and supports continuous or triggered readout [6, 8]. First MPW (Multi-Project Wafer) submission was done in April 2013 and further developments are ongoing.

Online and offline reconstruction and calibration are very challenging due to the demand of data compression and requirement of the space-charge distortion corrections. Currently a two-stage reconstruction scheme is under consideration. In the first stage of the reconstruction, an averaged space-charge distortion map scaled to the averaged multiplicity for certain time intervals is used for the distortion corrections, and cluster finding and cluster-track association are performed, which leads to a data compression by a factor of 20. Full tracking with the external detectors (Inner Tracking System + Transition Radiation Detector) will be performed in the 2nd stage of the reconstruction, where

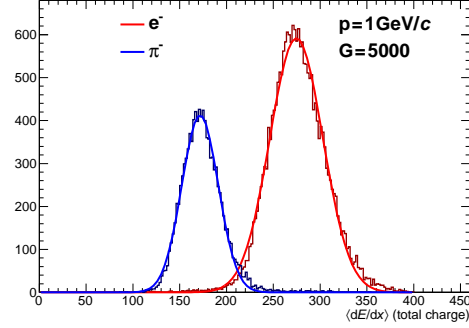


Figure 2.  $dE/dx$  spectrum of 1 GeV/c electrons and pions recorded at a gain of  $\sim 5000$  measured with an IROC prototype employing a triple stack of large-size GEM foils. (Y-axis shows the number of counts and X-axis shows  $dE/dx$  (a.u.).)

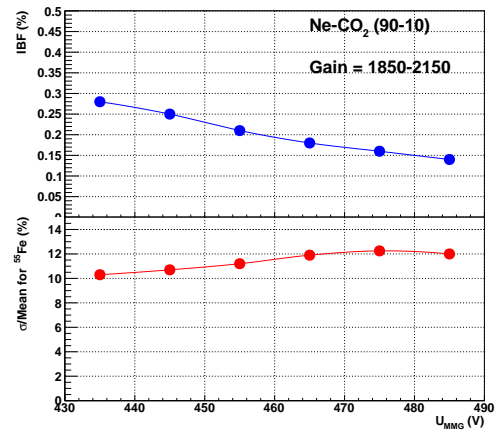


Figure 3. Upper: IBF as a function of voltage at mesh for 2 GEM + MM system. Bottom: Energy resolution as a function of voltage at mesh for 2 GEM + MM system

a high-resolution space-charge map being updated every 5 msec is generated for the full distortion corrections. Figure 4 shows the expected  $p_T$  resolution in 50 kHz Pb-Pb collisions without any space-charge distortions (left), with space-charge distortion and distortion corrections at the first stage (middle), and with space-charge distortion and full distortion corrections at 2nd stage of reconstruction (right). In these calculations, space-charge fluctuations mainly due to the number of pileup events and charged particle multiplicities are taken into account. The obtained  $p_T$  resolution after the 2nd reconstruction stage is comparable to that without distortions, if TPC-ITS global tracks are considered.

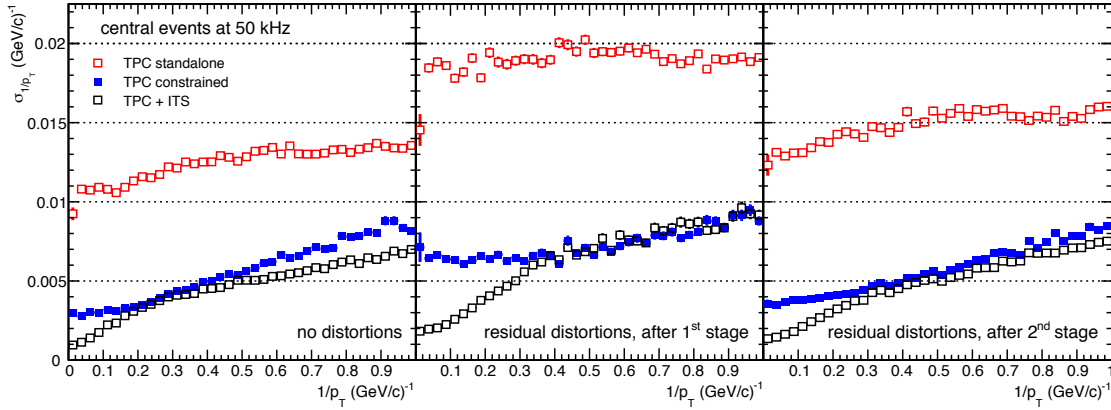


Figure 4. Comparison of the momentum resolution without distortions (left) and with residual distortions after the first (middle) and second (right) reconstruction stage in Pb-Pb collisions at 50 kHz

#### 4. Summary and Outlook

To exploit the full potential of the high luminosity of the LHC in RUN 3, the ALICE program for RUN 3 requires an upgrade of the TPC. The heart of the TPC upgrade is to replace the MWPC-based readout chambers by detectors employing micro-pattern detectors including GEMs to allow TPC operation in continuous mode. Extensive detector R&D and simulations have been conducted and a baseline scenario for the detector design has been established. Quadruple stacks of GEM layers with different GEM pitches provide the required IBF and energy resolution. Also a design based on a hybrid configuration of GEMs and Micromegas is studied. Simulations show that the performance of the present TPC can be retained in 50 kHz Pb-Pb collisions after distortion corrections. Further studies of the long-term stability, uniformity of the gain and IBF, and discharge probability are being conducted. IROC prototypes employing a 4-GEM stack and a hybrid 2-GEM + MM system are being built and beam tests will be carried out at the PS and the SPS in the fall of 2014.

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